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WADC TECHNICAL REPORT 52-257

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**LUMINANCE THRESHOLDS FOR THE RESOLUTION OF VISUAL DETAIL DURING
DARK ADAPTATION FOLLOWING DIFFERENT DURATIONS
OF LIGHT ADAPTATION**

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Statement A
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**LUMINANCE THRESHOLDS FOR THE RESOLUTION OF VISUAL DETAIL DURING
DARK ADAPTATION FOLLOWING DIFFERENT DURATIONS
OF LIGHT ADAPTATION**

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April 1952

*Aero Medical Laboratory
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**Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio**

FOREWORD

This report was prepared by Columbia University under USAF Contract No. AF 33(C38)-22616 covering work on Visual Factors in Cathode Ray Tube Data Presentation. The contract was initiated under a project identified by Research and Development Order No. 694-45, Presentation of Data on Radar Scopes, and was administered by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Kenneth T. Brown acting as Project Engineer.

ABSTRACT

Luminance thresholds for the visual resolution of various widths of alternating light and dark lines were determined at various times during recovery from different durations of light adaptation. Increasing duration of preadaptation from one second to five minutes raises the initial dark adaptation thresholds and decreases the speed of the recovery process. The level of visual acuity determines the range of luminance covered by the dark adaptation curves.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:



ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

The progress of dark adaptation of the eye depends to a marked extent upon the initial state of light adaptation. Varying either the intensity of the preadapting light or the duration of the pre-exposure affects the course of the subsequent increase in sensitivity during a stay in the dark. This adaptation process is ordinarily traced by determining the luminance threshold, the lowest luminance of light which can be detected, at various intervals of time until it has reached a fairly stable level. In general, measurements of the eye as a whole show a primary rapid drop in threshold during the first few minutes, and a later more gradual drop in threshold which proceeds for over 30 minutes. The early part of the curve corresponds to cone adaptation; the secondary decline is a function of the rods (Hecht, 5).

Studies by Winsor and Clark (10), Wald and Clark (9), Hecht, Haig, and Chase (6), Haig (3), and Mote and Riopelle (8), show that duration and luminance of pre-exposure have certain similar effects upon the shape of the luminance threshold curve. For regions which include both the fovea and the periphery the presence of two distinct sections of the curve, representing both cones and rods, requires a relatively large amount of previous light adaptation. Following brief exposures and low luminances, cone adaptation is extremely rapid, and only the secondary rod portion is in evidence. The higher the luminance of the preadapting light and the longer the period of pre-exposure, within limits, the more the initial threshold values are raised, the later does the rod adaptation appear, and the longer the time required for the threshold to reach a final steady value.

While different investigators agree on the general results just outlined, it is a question whether the luminance of the pre-exposure light and the duration of the pre-exposure have identical effects upon the course of dark adaptation. A chemical formulation of the visual cycle, proposed by Wald and Clark (9), predicts that recovery of the rods from short intense flashes of light will be faster than recovery from prolonged exposures to lower intensities. This prediction was supported by their data. Following the short duration and high intensity the rod adaptation curve was so rapid that it overtook and crossed the long duration, high intensity curve. Recent experiments have sought to furnish dark adaptation data for preadaptation conditions under which the product of intensity and duration of pre-exposure was a constant. For the peripheral retina, Haig (3) found that an increase in the degree of light adaptation, whether produced by raising the luminance or by prolonging the exposure, affected subsequent rod dark adaptation in an identical manner.

In the fovea, Mote and Riopelle (8) using four intensities (11,300, 5,650, 1,130, and 565 ml.) and four durations (300, 150, 30, and 15 seconds), showed that the curves are the same for $I \times t = C$ for the two higher intensities and two longer durations, and also for the two lower intensities and two shorter durations. For other values of $I \times t = C$ the curves were generally not the same. "On the whole, the lower intensity, longer duration curves have lower initial threshold values, steeper slopes, and

sooner reach a final steady threshold value than the curves for higher intensities and shorter durations." (p. 673).

Thus far we have considered the relation between dark adaptation and the previous light adaptation with reference to the luminance threshold for the detection of light. Besides the simple light detection threshold other criteria of sensitivity during dark adaptation are of considerable interest. A question of undoubted practical importance is how visual acuity, or the capacity of the eye for the resolution of visual detail, increases during dark adaptation. We need to know whether different visual resolution criteria respond in the same way to changes in the condition of preadaptation.

Recent data [summarized by Brown, (2)] suggest that the dark adaptation function is fairly independent of the particular criterion of threshold. Brown, Graham, Leibowitz, and Ranken (1) determined luminance thresholds for the resolution of grating test objects representing visual acuities of 1.0, 0.62, 0.25, 0.083, and 0.042 as well as for light detection following five minutes preadaptation to a luminance of 1500 millilamberts. Different degrees of visual resolution yielded similar results, with cone sections of the curves parallel to those for light detection.

In further extension of this research, Brown (2) studied the effect of varying the preadapting luminance upon the luminance threshold curves for different acuities. The resulting dark adaptation functions for the resolution of three different gratings corresponding to visual acuities of 0.62, 0.25, and 0.042, have the same characteristic shape as the curves for light detection.

Two effects of the level of visual acuity were noted. First, visual acuity is a parameter which determines the position of the curve on the log luminance threshold axis. The higher the degree of visual acuity, the higher the position of the curve. Second, curves for the finer gratings, representing higher acuities, drop to a final steady level after about five to twelve minutes in the dark. Such curves characterize cone function. Only the coarser gratings will permit the characteristic rod portions of the dark adaptation curves to appear.

Since in both experiments the course of dark adaptation for different acuities was determined following a constant duration of pre-exposure (5 minutes), the results do not indicate what happens following pre-exposures of shorter or longer duration. The present experiment aims to remedy this lack by showing how luminance thresholds for the resolution of visual detail during dark adaptation vary as a function of preadapting duration.

The results should provide useful information which can be applied to several sorts of specific tasks from map or dial reading to visual search. Stated in practical terms the important problem is this: How luminous must a radar screen or dial markings be so that the operator can read them after scanning the sky for a brief length of time? What difference is caused by prolonging the original exposure to light? Will different tasks, requiring different degrees of acuity, be affected in the same way by given conditions of adaptation?

The very early part of the dark adaptation process is of particular interest. We need a precise description of the sensitivity of the eye during the first minute following different amounts of light adaptation. By making frequent determinations of threshold during the primary dark adaptation period we hope to provide these wanted data.

Specifically, the present experiment is concerned with the following questions:

(1) How does the luminance threshold for a given acuity level vary as a function of time in the dark, following different durations of pre-exposure?

(2) What is the precise course of such luminance threshold curves at successive fifteen second intervals during the first minute following pre-exposure and at subsequent one or two minute intervals of dark adaptation?

(3) What is the effect of level of visual acuity?

(4) With respect to visual acuity criteria, does duration of pre-exposure influence the subsequent dark adaptation in the same way as luminance of pre-exposure? While the present experiment does not vary both intensity and duration of preadaptation, the results may be compared with those obtained by Brown (2) in a similar experiment on the course of dark adaptation for different visual acuity tasks as a function of pre-exposure intensity.

APPARATUS

The apparatus used was a modified Hecht-Shlaer adaptometer (7). Modifications enabling determination of acuity thresholds during dark adaptation are discussed in detail by Brown (2). Further modification in this experiment enabling determination of acuity thresholds, particularly during the early seconds of dark adaptation, are discussed in detail below.

The Hecht-Shlaer apparatus essentially involves two optical systems: The first is a light adaptation system which presents a Maxwellian view of a 35 degree circular field to which the subject light adapts. Let us consider the optical path of this system from light source to exit pupil. The light source consists of a 100 watt tungsten filament frosted bulb mounted behind a 22 mm. circular opening filled by flashed opal glass. This diffuses the light which is then controlled in luminance by neutral tint Wratten filters, and next collimated by a lens located at a focal distance of 12 cm from the flashed opal glass. A second lens then focuses the parallel light to a point 6 cm distant, where is located a 3 mm. exit pupil through which the subject sees a field of approximately 35 degrees diameter (visual angle). A fixation point at the center of this field is provided by a small cross scratched on a piece of plain glass located between the two lenses.

The second system is used during dark adaptation. This system, with which the experimenter can mechanically replace the first, enables flash presentation of a 7.3 degree test field during the dark adaptation period.

The light source, used in the first system, sends diffused light through a neutral Wratten wedge and balancer, a spring loaded camera shutter (the shutter was set at a speed of 0.016 sec. for the present experiment), and neutral Wratten fixed filters, before being made parallel by the collimating lens. A circular field stop, 4.45 cm. in diameter placed in the path of the collimated beam, limits the test field to a visual angle of 7.3 degrees. A second lens of 36 cm. focal length, focuses the beam at the 3 mm. exit pupil. Fixation is provided by a red cross reflected into the center of the visual field by a .007 inch thick piece of cover glass located between the Wratten filters and the collimating lens.

A chin rest, used in both systems, is so positioned as to hold the subject's pupil directly in back of the 3 mm. exit pupil.

The modification enabling determination of acuity thresholds was made by Brown, Graham, Leibowitz and Ranken (1), and is discussed by Brown (2). This involved two minor changes in the Hecht-Shlaer dark adaptation system. First, a holder, into which gratings can be inserted was mounted between the wedge and neutral Wratten filters at an optical distance of 57.2 cm. from the exit pupil. Secondly, the red fixation cross was adjusted so that its optical distance to the exit pupil was approximately 57.2 cm. Thus accommodation for the cross and grating was essentially the same.

The modification enabling determination of acuity thresholds during the early seconds of dark adaptation involved the addition of two Microflex timers and the system diagrammed in Figure 1. This system enabled accurate timing, down to an interval of 1 second, of two periods: (1) the light adaptation period; and (2) the period between the end of light adaptation and the first flash during dark adaptation. With regard to the light adaptation period, during experimental procedure the system could be controlled either automatically or manually.

Automatic control worked as follows (see Figure 1): Switch S_2 remained closed throughout automatic procedure. The experimenter adjusted the optical system to that for light adaptation by moving lever L_1 located on the side of the apparatus. This also closed switch S_1 . Solenoid C_1 was thus activated, and shutter SS was drawn upward cutting off the light from LS. Adjustment of lever L_1 also dropped the camera shutter, CS, from the light path, although this is not shown in Figure 1. Light adaptation was begun when the experimenter closed switch S_3 in the "starter" circuit of timer A. Contact A_2 closed immediately, and relay B_1 opened. This released shutter SS, allowing light to pass through to the subject. After a particular duration of light adaptation as set on timer A, A_2 opened and shutter SS again cut off the light from LS, ending light adaptation.

As soon as light adaptation ended, the experimenter moved lever L_1 up so that the dark adaptation system was moved into position, and shutter CS was in the light path. (Moving the lever up also opened switch S_1 , thus reopening shutter SS.) Change to the dark adaptation system had to be accomplished in less than one second, since when light adaptation ended, contact A_3 closed and timer B was started. One second thereafter B_3 closed and the camera shutter CS was tripped automatically. In this way, a test flash was presented to the subject precisely one second after light adaptation ended.

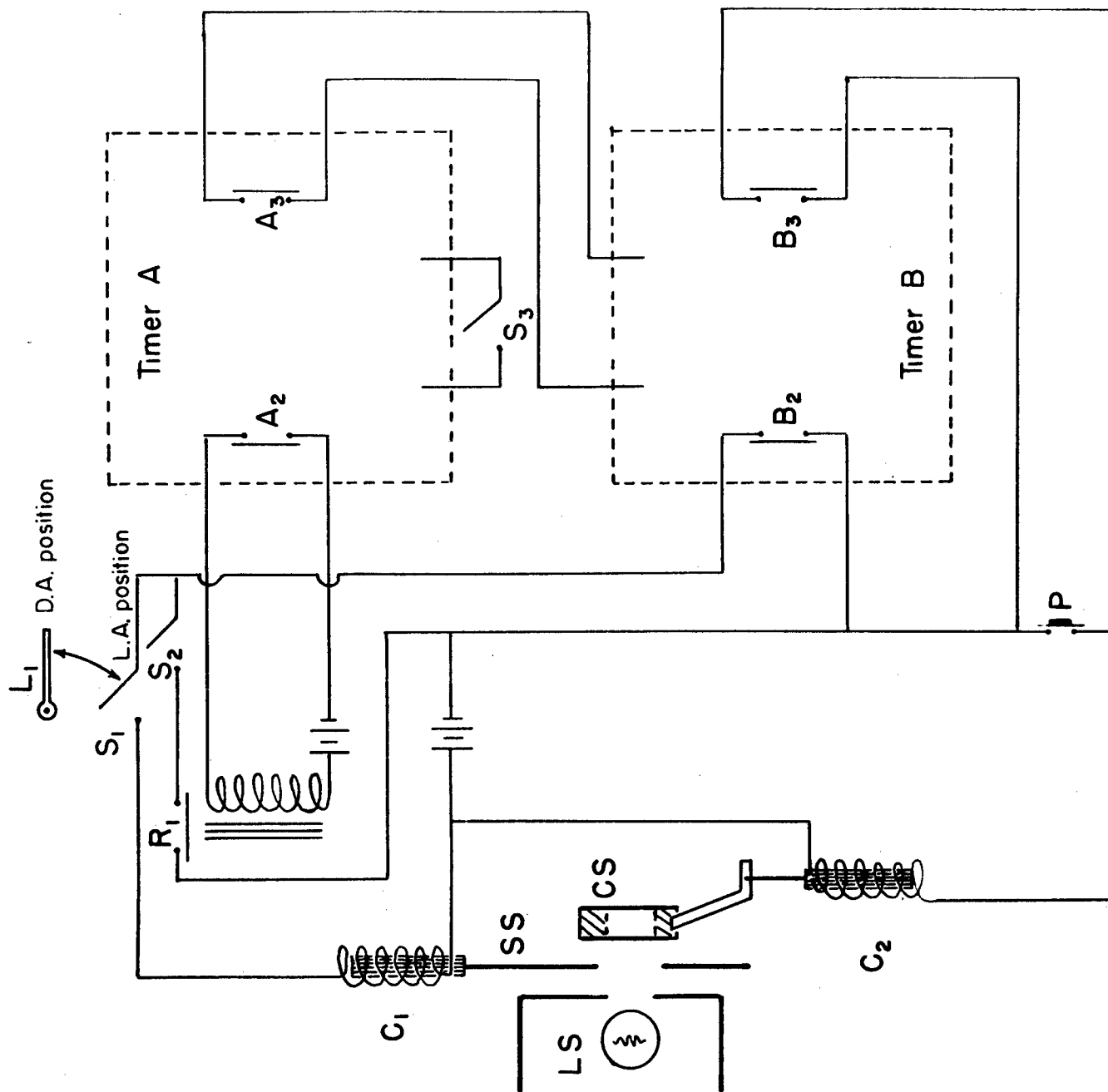


Figure 1. Diagram of the apparatus.

Manual control was used for light adaptation periods of more than two minutes, which is the limit of both timers A and B. S_2 remained open throughout manual procedure. When the light adaptation system was set in place, light adaptation began immediately. To end light adaptation the experimenter closed S_3 . This started timer B and closed shutter SS simultaneously. The experimenter immediately replaced the light adaptation system with the dark adaptation system by shifting lever L_1 . This had to be done in less than one second since shutter CS was tripped automatically one second after timer B was started.

The experimenter pressed push button, P, to present flashes to the subject after one second. This was done after either manual or automatic operation.

Calibration of the apparatus followed the same procedure described in detail by Brown (2). This involved four general considerations: (1) the luminance of the light adapting field; (2) the luminance of the test (dark adapting) field; (3) the visual angles subtended at the eye by the lines on the gratings; and (4) the densities of the neutral Wratten wedge and fixed filters.

The luminance of the light adapting field was determined by a binocular luminance match with a standard field of equal area calibrated for luminance with the Macbeth Illuminometer. Its maximum was 14,800 ml. with the 100 watt bulb operated at 120 volts.

The luminance of the test field was determined by a monocular luminance match using the comparison standard provided with the apparatus. The luminance of the standard field was calibrated with the Macbeth Illuminometer. By varying the wedge, the subject was able to match the two fields in luminance. The maximum luminance of the test field was thus determined to be 15,140 ml when the 100 watt bulb was run at 120 volts.

Three gratings, described by Shlaer (1937), were used in the experiment. The grating lines were opaque and separated by transparent spaces of width equal to that of the lines. The visual angle subtended by the distance between the contours on these gratings was calculated from the known width of the lines, the magnification of the optical system, and the optical distance of the grating image from the eye. The visual acuities of the three gratings used were respectively, 0.042, 0.083, and 0.62.

The filter densities were determined on a Martens photometer. The wedge density was checked by placing several different filters of known density in the filter holder and adjusting the wedge to obtain a match with the monocular matching device described above. The differences in settings of the wedge were then checked against the differences in density of the filters for which the settings were obtained.

METHOD AND PROCEDURE

The present experiment investigated threshold luminance for an acuity object as a function of time in dark after exposure to a 1000 ml adapting field. Two parameters of this function also studied were: (1) duration of light adaptation; the durations used were 1 sec., 30 sec., 5 min., and 10 min.; and (2) the acuity value of the grating used in the test field; the acuity values of the 3 gratings used were 0.042, 0.083, and 0.62 respectively. Since for the 0.083 acuity value there were no appreciable differences between the dark adaptation curves following 5 and 10 minutes light adaptation, the 10 minute duration was omitted for the two other acuity values; this was done primarily in the interest of shortening the relatively lengthy procedure required in this experiment.

A modified psychophysical method of constant stimuli was used to determine the acuity thresholds during dark adaptation. For each point on the dark adaptation curve, flashes of 0.016 sec. were presented to the subject with the grating randomly in positions 45 degrees clockwise, 45 degrees counterclockwise, or vertical. The subject responded "right", "left", "vertical" or "no". For each point, from 2 to 5 responses were necessary such that at least one negative and one correct response were obtained. The threshold luminance at a point was then determined as the mean of the highest flash luminance at a "no" response and the lowest flash luminance at a correct response. Incorrect responses were counted as "no" responses.

This method was used because the traditional constant stimuli method would have required a prohibitive amount of time. The method of limits, used by Hecht (7), could not be used since threshold luminance for resolution of gratings is considerably higher than that for light detection; thus test flashes given at intervals of less than 10 seconds might have altered the course of dark adaptation.

Data were collected for two observers, one male, A.D., and the other female, A.G. Both observers had normal vision. The right eye of A.D. and the left eye of A.G. were used in all determinations.

The procedure during one experimental run involved a pre-light adaptation period, a light adaptation period, and a dark adaptation period.

During pre-light adaptation, the observer sat in the dark room until his visual sensitivity reached a constant minimum level. The experimenter determined the constancy of sensitivity by presenting the subject every two minutes with flashes of the test grating to be used, until the threshold luminance of the test flash was at a minimum and did not decrease by more than 0.2 log ml, over a period of 4 minutes. The subject was then given a 15 second warning for light adaptation at which time he positioned his head by means of the chin rest and looked through the 3 mm. exit pupil at the red fixation light. Another warning was given 5 seconds before light adaptation at the end of which time light adaptation was begun.

The experimenter began light adaptation in one of two ways: automatically or manually. On automatic, the light adaptation system was thrown in (lever L_1 thrown down) just before the 15 second warning. Then the experimenter had to close S_3 for light adaptation to begin. On manual the light adaptation system was thrown in at the end of the 15 second warning at which time light adaptation began.

During light adaptation the subject fixated a black cross located in the center of the field. Just before the end of light adaptation 15 second and 5 second warnings were given, and the dark adaptation period began.

During the first minute of dark adaptation, flashes were given at 1, 15, 30, 45, and 60 seconds. In a check experiment, it was found that reduction of the interval between flashes to as little as 10 seconds did not systematically or appreciably change the shape of the dark adaptation curve. A 15 second flash interval was, therefore, used during the first minute. Flashes were then presented every minute, or every two minutes, until the dark adaptation curve reached a relatively constant minimum level or until 30 minutes had passed. The level of the dark adaptation curve was assumed to be relatively constant when the threshold luminance did not change by more than 0.2 log ml. over a period of 4 minutes; and the level was assumed to be at a minimum when the curve was either at the cone levelling off portion or the rod levelling off portion, depending upon the particular grating used. For example, according to data collected by Brown, Graham, Leibowitz and Ranken (1), the 0.62 acuity dark adaptation curve reaches a minimum threshold at the cone levelling off portion of the curve; our 0.62 acuity curves were thus ended along the cone level. These criteria, concerning a constant minimum level, depend primarily upon determinations, made by the above authors, of the appearance of the rod cone break in the dark adaptation curve, which determinations are substantiated by Brown (2). These criteria are thus felt justified, especially in view of the time gained in experimentation.

It was also found convenient, for the second and succeeding minutes, to present flashes 30 and 15 seconds before the minute. This provided information enabling the experimenter to obtain a more accurate bracket, between a correct and a negative response, for each minute.

It was found that for the short light adaptation durations, up to 3 or 4 runs could be obtained in one experimental session. That is, each experimental point was determined by from 2 to 5 flashes, which meant that from 2 to 5 pre-light, light, and dark adaptation sequences were necessary. During one session, then, the dark adaptation period of one run could serve as the pre-light adaptation period of the following run, experimental time therefore being minimized. Under no conditions, however, was the subject in the darkroom for a continuous period of longer than 1 1/2 hours. This meant that for the longer light adaptation durations only one or two runs were possible in one session.

RESULTS

The data have been organized into two basic functions, each described with respect to the parameters investigated. First, let us consider threshold luminance for an object of constant acuity as a function of time in the dark

following exposure to a light of a constant luminance. A parameter of this function investigated involved the duration of light adaptation. See Tables I, II, and III and Figures 2, 3, and 4. The experimental procedure followed in obtaining the data in Figures 2, 3, and 4 varied only with respect to the acuity values of the grating used (specified in each Figure).

The data are described separately for each observer. There seems to be no significant difference between these two observers for any of the curves in Figures 2, 3, and 4.

The following observations may be made with regard to these curves. They are generally similar in form to the acuity dark adaptation curves obtained by Brown, Graham, Leibowitz and Ranken (1) and Brown (2). They are steep during the early minutes of dark adaptation, and in some of these curves a break occurs which is usually explained in terms of the rod-cone Duplicity theory described by Hecht (5).

The influence of light adaptation duration as a parameter of the function in Figures 2, 3, and 4 becomes evident in the disappearance of this rod-cone break for the shorter durations of light adaptation. Two other effects occur as the duration of light adaptation is decreased: There is a shift of the rod-cone break toward the early portion of the dark adaptation curves along the time axis, and the curves begin at lower threshold luminances and reach asymptotic levels more quickly.

With respect to differences between Figures 2, 3, and 4, i.e., between the different gratings used, there does not seem to be much change in threshold luminance values between a grating of an acuity value of 0.083 and one of an acuity value of 0.042 (see Figures 2 and 3). However, a marked change occurs with the use of a grating of an acuity value of 0.62 (see Figure 4). This change is first evidenced in the disappearance of the rod-cone break. Further, it is seen that the differential effect upon threshold luminance of light adaptation duration is minimized. There is a slight displacement towards lower threshold luminances when light adaptation duration is reduced from 5 minutes to 30 seconds, but no appreciable, further decrease in threshold luminance level when light adaptation is reduced from 30 seconds to 1 second duration. Finally, the threshold luminance for the 0.62 grating during dark adaptation following all three light adaptation durations is considerably higher than that for the 0.042 and 0.083 gratings. (These general observations are more specifically described in discussion of Figure 6 below.)

Let us now consider the second function, threshold luminance as a function of the duration of light adaptation. Two parameters may be described with respect to this function: (1) time in the dark (see Figure 5); and (2) the acuity value of the test object (see Figure 6). The data for the two observers are averaged in Figures 5 and 6. This seemed justifiable in view of the general agreement between the data of the two observers in Figures 2, 3, and 4. It also seemed advisable in the interest of greater reliability of the points determining the function.

First, with general regard to the function itself, there is seen a steep rise in the curve from one second to approximately five minutes of

TABLE I

Log threshold luminance in millilamberts during dark adaptation after different durations of light adaptation. Visual acuity = 0.042. Subjects AD and AG.

Time in dark	Duration of Light Adaptation					
	1 sec.		30 sec.		5 min.	
	AD	AG	AD	AG	AD	AG
1 sec.	-0.60	-0.60	-0.45	-0.30	0.24	0.79
15 "	-1.48	-1.50	-0.85	-0.90	0.14	0.14
30 "	-1.66	-1.55	-1.00	-1.05	-0.16	0.11
45 "	-2.01	-1.75	-1.25	-1.25	-0.36	-0.21
60 "	-2.06	-1.85	-1.20	-1.35	-0.56	-0.56
2 min.	-2.21	-2.21	-1.41	-1.61	-1.00	-0.90
3 "	-2.31	-2.41	-1.46	-1.61	-1.25	-1.35
4 "	-2.26	-2.51	-1.61	-1.61	-1.45	-1.40
5 "	-2.31	-2.46	-1.61	-1.71	-1.45	-1.45
6 "	-2.56	-2.71	-1.61	-1.71	-1.40	-1.45
7 "	-2.41	-2.51	-1.81	-2.11	-1.40	-1.60
8 "	-2.56	-2.66	-2.01	-2.11	-1.55	-1.55
9 "	-2.66	-2.66	-2.16	-2.26	-1.50	-1.55
10 "	-2.66	-2.61	-2.46	-2.41	-1.55	-1.70
11 "	-2.61	-2.76	-2.36	-2.46	-1.55	-1.75
12 "	-2.76	-2.71	-2.51	-2.46	-1.36	-1.36
13 "	-2.66	-2.71	-2.56	-2.61	-1.61	-1.61
14 "	-2.86	-2.86	-2.71	-2.61	-1.81	-1.76
15 "	-2.91	-2.86	-2.71	-2.76	-1.91	-1.86
16 "	-2.86	-2.86	-2.71	-2.86	-1.96	-2.06
17 "	-2.86	-2.86	-2.71	-2.81	-2.14	-2.46
18 "	-2.91	-3.01	-3.01	-2.81	-2.14	-2.56
19 "	-2.86	-2.96	-2.86	-2.91	-2.19	-2.56
20 "		-2.96	-3.11	-3.01	-2.39	-2.56
21 "			-2.91	-3.01	-2.39	-2.56
22 "			-2.96	-2.91	-2.44	-2.66
23 "			-3.11	-3.06	-2.54	-2.76
24 "			-3.01	-3.06	-2.54	-2.66
25 "					-2.79	
26 "					-2.69	

TABLE II

Log threshold luminance in millilamberts during dark adaptation after different durations of light adaptation. Visual acuity = 0.083. Subjects AD and AG.

Time in dark	Duration of Light Adaptation							
	1 sec.		30 sec.		5 min.		10 min.	
	AD	AG	AD	AG	AD	AG	AD	AG
1 sec.	-0.65	-0.55	-0.30	0.17	0.94	0.99	0.99	1.09
15 "	-1.35	-1.45	-0.73	-0.73	0.39	0.14	0.59	0.29
30 "	-1.64	-1.70	-0.93	-0.78	0.14	-0.06	0.14	-0.01
45 "	-1.76	-1.95	-1.30	-0.90	0.00	-0.11	-0.06	-0.11
60 "	-2.06	-2.10	-1.35	-1.30	-0.16	-0.46	-0.31	-0.41
2 min.	-2.21	-2.20	-1.33	-1.47	-0.99	-0.01	-0.90	-1.05
3 "	-2.31	-2.30	-1.63	-1.43	-1.24	-1.12	-1.25	-1.20
4 "	-2.06	-2.35	-1.76	-1.62	-1.22	-1.12	-1.25	-1.35
5 "	-2.71	-2.50	-1.78	-1.70	-1.37	-1.27	-1.25	-1.40
6 "	-2.71	-2.55	-1.86	-1.70	-1.27	-1.37	-1.50	-1.40
7 "	-2.31	-2.45	-2.06	-1.93	-1.12	-1.63		-1.40
8 "	-2.86	-2.45	-2.16	-1.90	-1.42	-1.72	-1.60	-1.40
9 "	-2.51	-2.50	-2.31	-2.10	-1.32		-1.45	-1.30
10 "	-2.51	-2.40	-2.31	-2.11	-1.32	-1.61	-1.45	-1.50
11 "							-1.55	-1.35
12 "	-2.71	-2.40	-2.41	-2.25	-1.52	-1.81	-1.60	-1.70
13 "								
14 "	-2.41	-2.40	-2.56	-2.45	-1.56	-1.76	-1.53	-1.95
15 "								
16 "	-2.41	-2.35	-2.46	-2.56	-1.61	-1.76	-1.82	-2.00
17 "								
18 "	-2.61		-2.61	-2.65	-1.95	-2.00	-2.01	-2.16
19 "								
20 "	-2.71		-2.61	-2.56	-2.15	-2.11	-2.16	-2.21
21 "								
22 "	-2.61		-2.81	-2.71	-2.15	-2.00	-2.16	-2.46
23 "								
24 "	-2.61		-2.81	-2.55	-2.25	-2.21	-2.26	-2.56
25 "								
26 "			-2.86		-2.30	-2.05	-2.31	-2.51
27 "								
28 "			-2.91		-2.40	-2.10	-2.41	-2.66
29 "								
30 "					-2.50	-2.31	-2.47	-2.56

TABLE III

Log threshold luminance in millilamberts during dark adaptation after different durations of light adaptation. Visual acuity = 0.62. Subjects AD and AG.

Time in dark	Duration of Light Adaptation					
	1 sec.		30 sec.		5 min.	
	AD	AG	AD	AG	AD	AG
1 sec.	1.04	0.69	1.60	1.05	2.43	2.43
15 "	0.19	0.54	0.80	0.65	1.58	1.45
30 "	-0.31	0.24	0.00	0.45	1.48	1.62
45 "	-0.21	0.04	0.25	0.25	1.53	1.25
60 "	-0.41	0.14	0.10	0.10	0.88	1.21
2 min.	-0.26	-0.01	-0.60	-0.41	0.19	0.59
3 "	-0.26	-0.01	-0.36	-0.46	0.14	0.29
4 "	-0.26	-0.36	-0.26	-0.61	0.09	-0.21
5 "	-0.16	-0.46	-0.36	-0.66	0.04	-0.41
6 "	-0.31	-0.21	-0.36	-0.51	-0.06	0.02
7 "	-0.21	-0.41	-0.31	-0.36	0.14	0.04
8 "	-0.31	-0.21	-0.21	-0.46	0.09	-0.01
9 "	-0.31	-0.46	-0.36	-0.46	-0.06	-0.21
10 "	-0.26	-0.46	-0.36	-0.41	-0.06	-0.16
11 "	-0.31	-0.51	-0.51	-0.61	0.04	-0.31
12 "	-0.21	-0.61	-0.36	-0.56	-0.06	-0.11
13 "		-0.76	-0.41		-0.21	-0.16
14 "		-0.71	-0.56		-0.16	

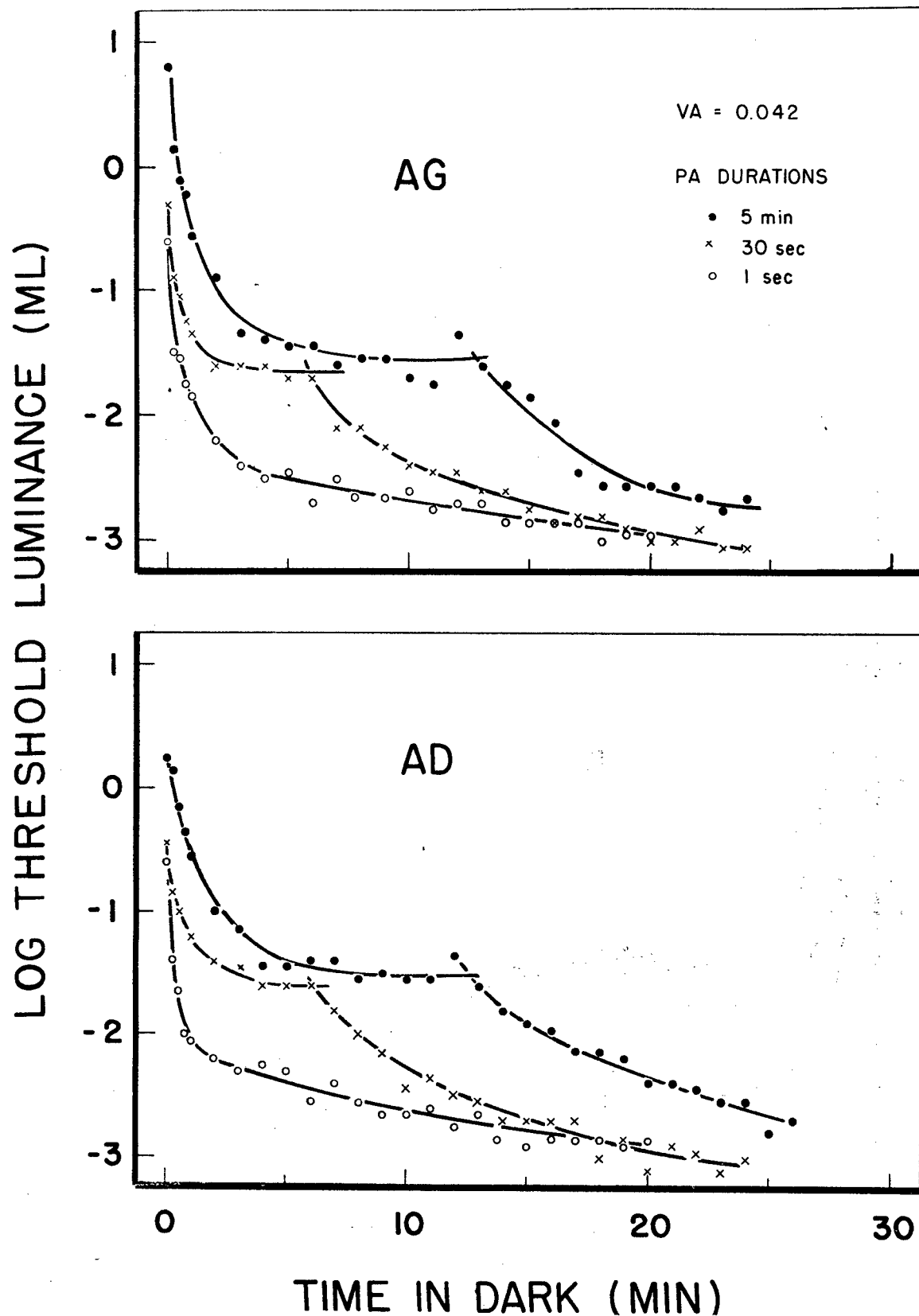


Figure 2. Dark adaptation curves for visual acuity (VA) = 0.042 following 5 min., 30 sec., and 1 sec. preadaptation (PA) to a constant luminance of 1000 ml. Subjects AG and AD.

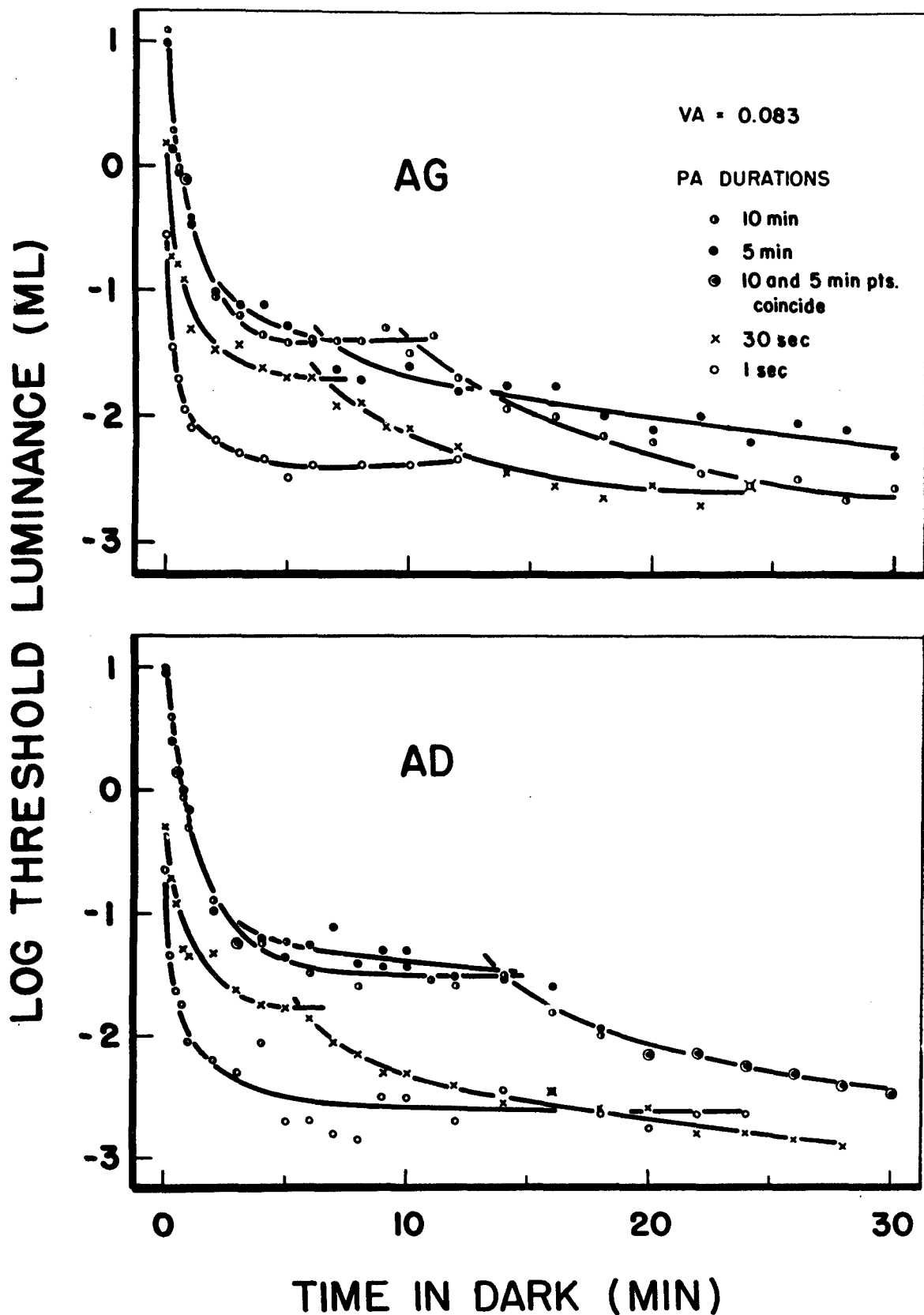


Figure 3. Dark adaptation curves for visual acuity (VA) = 0.083 following 10 min., 5 min., 30 sec., and 1 sec. preadaptation (PA) to a constant luminance of 1000 ml. Subjects AG and AD.

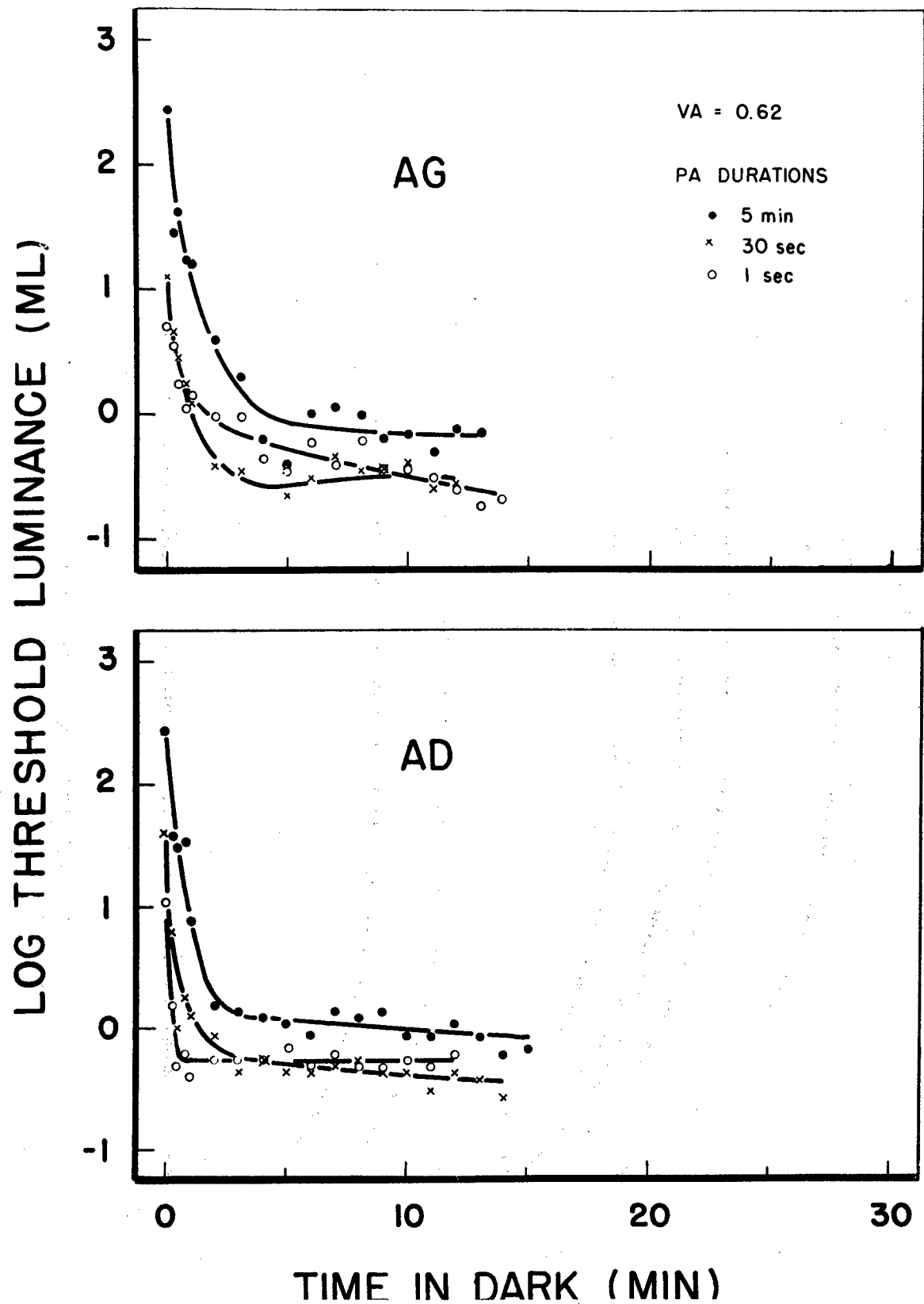


Figure 4. Dark adaptation curves for visual acuity (VA) = 0.62 following 5 min., 30 sec., and 1 sec. preadaptation (PA) to a constant luminance of 1000 ml. Subjects AG and AD.

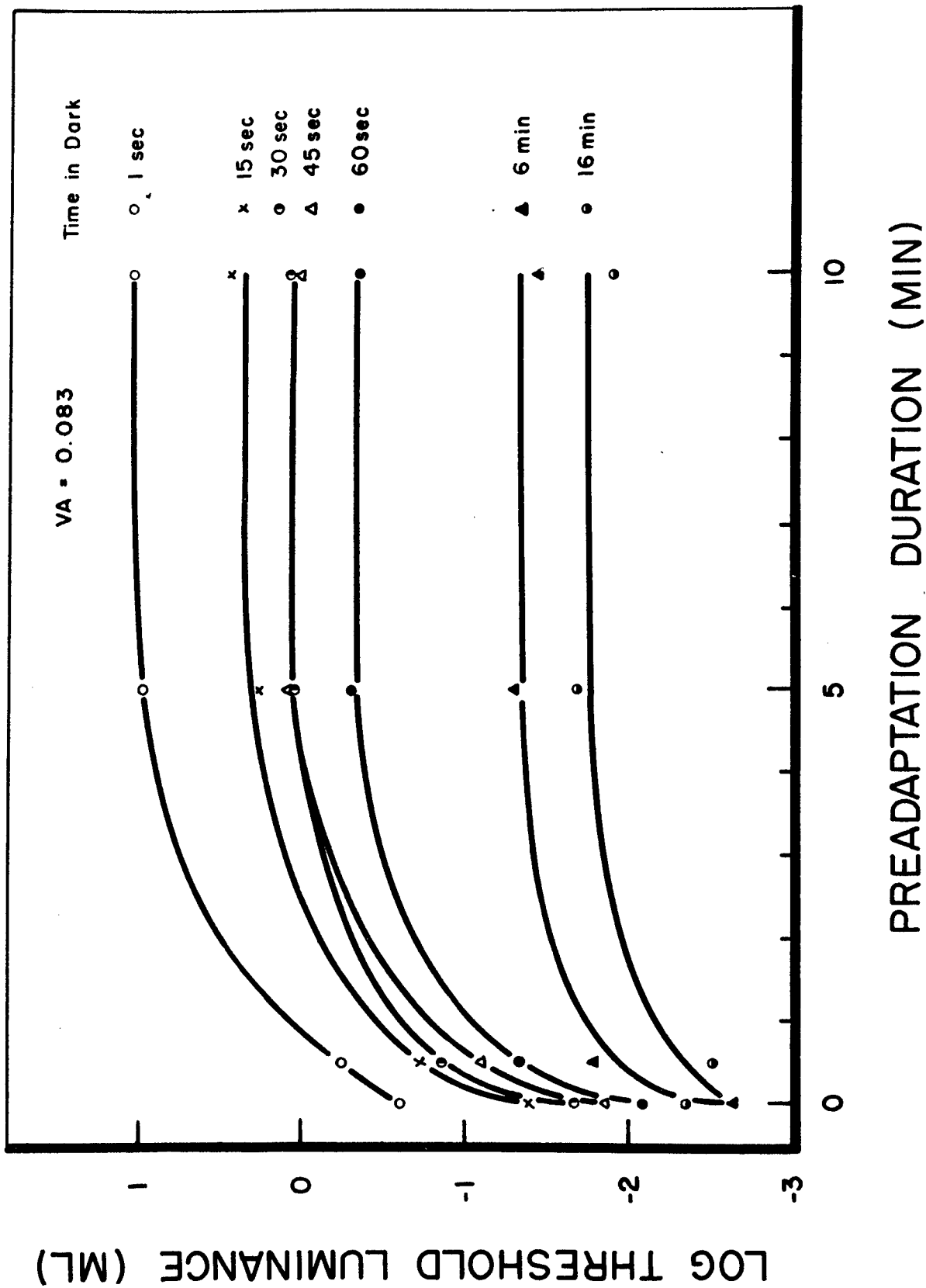


Figure 5. Luminance thresholds after various times in the dark as a function of the duration of preadaptation to a luminance of 1000 ml. Visual acuity (VA) = 0.083. Data of subjects AD and AG have been averaged.

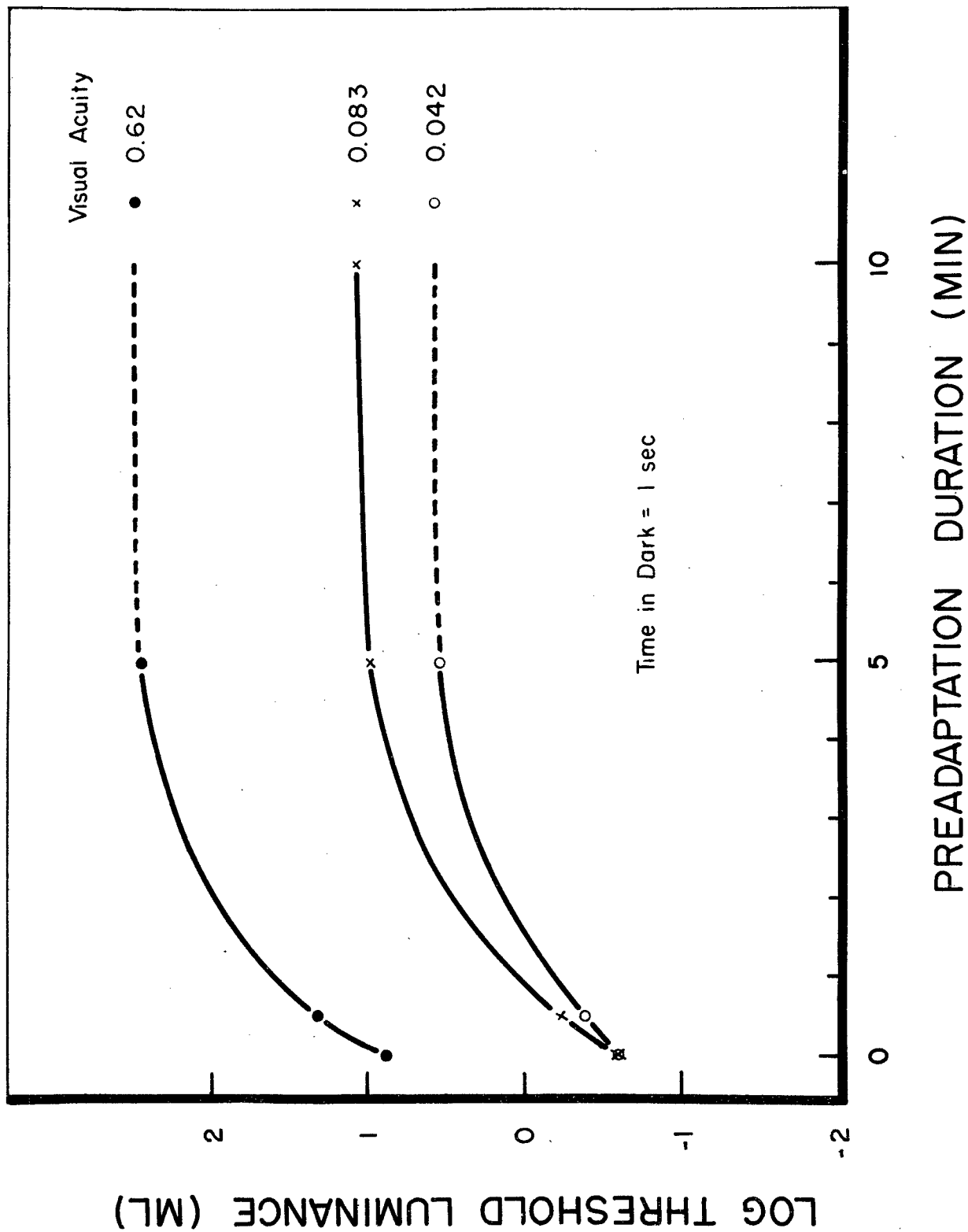


Figure 6. Luminance thresholds after 1 sec. dark adaptation for different levels of acuity as a function of duration of preadaptation to a luminance of 1000 ml. Data for the 10 minute duration were only secured for visual acuity = 0.083. Data of subjects AG and AD have been averaged.

light adaptation duration, after which little or no effect occurs up to ten minutes. It should be noted that whether the curve actually reaches a constant level at exactly five minutes cannot be determined from the data. The total change in threshold luminance, as the duration of light adaptation is changed from one second to five minutes, is between 1.5 and 2.0 log ml. in threshold.

With respect to the parameter of time in the dark, there is a downward displacement of the function along the log threshold luminance axis as time in the dark increases. Time in the dark does not significantly affect the form of the function, however, during the first minute of dark adaptation. It is only later in the course of dark adaptation that the function begins to become less steep. That is, duration of light adaptation has a marked effect upon the level of threshold luminance during the first minute in the dark but has much less effect after sixteen minutes in the dark.

Examination of the acuity parameter shows that during the first second of dark adaptation as the acuity necessary to resolve the test object increases, the threshold luminance also increases. For a change in acuity from 0.042 to 0.083, this holds only at the higher light adaptation durations. For a change in acuity from 0.083 to 0.62, however, the change in threshold luminance for resolution of the test object is marked for all light adaptation durations, constituting, on the average, an increase of approximately 1.5 log ml.

DISCUSSION

These results agree essentially with previous measurements of dark adaptation following different durations of light adaptation. Despite important differences in procedure and in criterion of threshold, the dark adaptation process is found to respond in much the same way to an increase in the period of light adaptation. Two effects are generally characteristic: As the exposure to light of a constant intensity lengthens, 1) the initial thresholds rise, and 2) the speed of dark adaptation decreases. A third effect occurs when the threshold criterion is sufficiently low to permit rod response. In this case the longer the pre-exposure, the more prominent is the primary cone dark adaptation and the more delayed is the secondary rod adaptation.

With regard to the initial rise in threshold, a comparison of Figure 5 with the plot of thresholds at 6 minutes in the dark following various lengths of exposure to 333 ml, presented by Wald and Clark (1937), shows both figures to be generally similar. Both figures express the fact that as duration increases, the threshold rises, at first rapidly, then more slowly, finally becoming constant in about 5 to 10 minutes.

With respect to this function the data of Hanes and Williams (4) (See Figure 2, p. 368) are also of interest. They measured the effect of varying durations of light adaptation upon the time required for detection of supra-threshold signals appearing on a typical cathode ray tube screen. The luminance of the signal was varied as one of the parameters of the

function of detection time versus duration of light adaptation. Thus, their situation required light adaptation for a certain duration and then dark adaptation until the eye became sensitive enough to just detect a target of a certain luminance. We might therefore expect that their curves of detection time versus duration of light adaptation, with target luminance as a parameter, should be similar to our curves of log threshold luminance versus duration of light adaptation, with time in the dark as a parameter. We might expect this similarity because detection time is determined by a threshold response (when the subject just begins to see the target) and also because we are, in effect, changing target luminance when we select different values of time in dark, since the target, or test field, in the present study is actually at different luminances, depending upon the change in sensitivity during dark adaptation.

What is expected is generally borne out. That is, both the Hanes and Williams data and our own show that beyond approximately five minutes, the duration of light adaptation has no appreciable effect on subsequent sensitivity in the dark. Also, the longer the time in the dark following light adaptation (or the dimmer the target or test field), the smaller the differential effect of different durations of light adaptation.

With respect to the relation between duration of light adaptation and the speed of subsequent dark adaptation, a comparison of the one second function with the other curves in Figures 2 and 3 is illustrative. Dark adaptation for the lower acuity levels is very much more rapid following one second of irradiation than it is following longer exposures. The one second curve reaches a constant minimum within about 12 minutes, while curves for the longer durations are still incomplete after 30 minutes in the dark.

The change in rate of dark adaptation was shown by Haig (3) and by Wald and Clark (9) to apply to rod dark adaptation exclusive of cone functioning. Haig identified two components in this change of rate, a decrease in the slope of the function, and a displacement to the right on the time axis. With increasing pre-adaptation the latter effect is evident in the curves of Figures 1 and 2. The rod portions of these curves are displaced increasingly to the right on the time axis as duration of preadaptation increases. The alteration in slope of the dark adaptation functions is less clear. Following exposures to light longer than one second the early portions of rod dark adaptation are hidden behind the cone function, and changes in velocity of rod adaptation cannot be detected. More data following lower luminances of the adapting light appear to be needed in order to obtain a sufficient number of purely rod functions for comparison.

While our experiment does not permit a definite answer to the question of the relative influence of duration and luminance of pre-adaptation upon the dark adaptation process for different acuities, the effects of varying duration are very similar to the effects of varying luminance shown by Brown (2). In general, the initial thresholds are lower, and the time required for complete dark adaptation decreases rapidly as

either the luminance or the duration of the pre-adapting light decreases. With regard to the form of the acuity dark adaptation curves, the influence of both duration and luminance of pre-exposure is most marked during the early stage of dark adaptation. Progressively less effect appears as time in the dark increases. In our data, the disappearance of a definite rod-cone break after brief exposures to light parallels Brown's finding for low luminances. However, a strict comparison of the portions of the two studies in which the total quantity of previous light adaptation was the same, but of lower luminance and longer duration in one case, higher luminance and shorter duration in the other, yields a discrepancy. No rod-cone breaks were found by Brown following 5 minutes exposure to 100 ml (and lower). Our curves for the same acuity (0.042), using 30 sec. of preadaptation at 1000 ml, show the break in the case of both observers. This is apparently a departure from a reciprocal relation between time and luminance of light adaptation (cf 8).

With regard to the effect of the level of visual acuity, the present data agree very well with those of Brown. Taken together with the findings of Brown, Graham, Leibowitz and Ranken (1), these three studies clearly establish the independence of the form of the dark adaptation function from the criterion of threshold. Visual acuity determines the level of luminance covered by the dark adaptation curve. As the acuity required for the resolution of the test object increases, the curves are displaced upward on the log luminance axis. Curves corresponding to the higher degrees of acuity represent cone functioning only, and drop to a final level after about 5 to 12 minutes in the dark.

SUMMARY

Dark adaptation curves representing three levels of visual acuity have been determined following preadaptation for from one second to ten minutes to a constant luminance of 1000 ml.

1) At all acuity levels, the initial thresholds rise, and the speed of dark adaptation decreases as duration of preadapting light increases from one second to approximately five minutes. These effects are less pronounced at the highest acuity investigated, 0.62. A threshold response at this level represents cone adaptation exclusively.

2) At lower acuities, 0.083 and 0.042, an additional effect occurs as a function of duration. The shorter the period of light adaptation, the less prominent is the primary cone dark adaptation, and the sooner does the rod dark adaptation appear.

3) Duration of light adaptation has a marked effect upon the level of threshold luminance early in the course of dark adaptation. The effect becomes progressively reduced as time in the dark increases.

4) As the level of acuity increases, the threshold luminance also increases, depending upon the amount of change in acuity and the pre-adapting duration.

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